Partners in Cognition: Extending Human Intelligence with Intelligent Technologies

GAVRIEL SALOMON DAVID N. PERKINS TAMAR GLOBERSON

We examine how technologies, particularly computer technologies that aid in cognitive processing, can support intellectual performance and enrich individuals' minds. We distinguish between effects with *and* of *a technology: Effects* with *occur when people work in partnership with machines, whereas effects* of *occur when such partnerships have subsequent cognitive spin-off effects for learners working away from machines. It is argued that effects both* with *and* of *depend on the individual's mindful engagement in the partnership. Such mind–machine collaborations also invite reexamination of prevailing conceptions of intelligence and ability: Are they properties of the individual or of the joint system? We respond to these dilemmas by offering two views, one emphasizing mainly the upgraded performance in a person–machine system of partnership, the other emphasizing more the educationally valued cognitive residue that can result. The use of computer tools to extend the reach of minds is briefly discussed within wider normative, theoretical, and practical contexts.*

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People have been making machines more "intelligent." Can machines make people more intelligent? More specifically, with the increasing use of intelligent computer programs, tools, and related technologies in education, it may be an opportune time to ask whether they have any effect on students' intellectual performance and ability. Moreover, some educators have found in intelligent technologies the vision of a new kind of education that empowers and liberates the mind as no pattern of educational practice has done to date (Papert, 1980, 1987; Pea, 1987). With such educational aspirations at high pitch, the question of the impact of intelligent technologies on human thinking and learning becomes all the more interesting in view of the imminent prospect of getting some empirical answers.

Two points need to be noted at the outset. First, by *intelligent technologies* we do not necessarily mean *artificial intelligence.* Many technologies that would not be considered instances of artificial intelligence are intelligent technologies in our sense. The ordinary hand calculator is an example. Although not artificially intelligent, it undertakes significant cognitive processing on behalf of the user and thus is a partner in what Pea (1989) has come to call "distributed intelligence." Second, although our attention is focused on computer technology, we are fully aware that computer technology, *in and of itself,* is of little interest. What is of interest and can potentially affect students' intellect are the kinds of programs and tools that can be used with this technology, as well as the kinds of activities that they afford. Thus, while we may speak of *computer technology,* we use this generic term only for the sake of brevity; as it will become apparent, our focus is primarily on computer tools and programs and on the learning activities that they enable.

With these points in mind, we turn to the influence of intelligent technologies on human intellectual performance and ability. In what follows, we outline a conceptual framework incorporating several crucial distinctions. First, we distinguish between two kinds of cognitive effects: Effects *with* technology obtained during intellectual partnership with it, and effects *of* it in terms of the transferable cognitive residue that this partnership leaves behind in the form of better mastery of skills and strategies. We notice that cognitive effects with computer tools greatly depend on the mindful engagement of learners in the tasks afforded by these tools and that there is the possibility of qualitatively upgrading the performance of the joint system of learner plus technology. This, in turn, challenges our conceptions of ability. Is it a measure of one's own endowment (an *analytic* conception), or is it a measure of one's performance when equipped with the right technology (a *systemic* conception)? We claim that because real-life decision making and reasoning are and will continue to be mainly a solo affair, we elaborate upon the analytic conception of ability in our discussion of how transferable cognitive effects of the technology can be attained, and we place within it initial findings from several sources. We notice that our initial question of technologies and minds needs to be reframed. Rather than asking how technology "naturally" affects minds, the way scholars studied the cognitive effects of literacy, one should ask how the partnership with it *can be made* to have transferable cognitive

GAVRIEL SALOMON *is Professor of Education at the University of Arizona, College of Education, Tucson, Arizona 85721. His specialization is education and cognitive psychology.* DAVID N. PERKINS *is Co-director of Project Zero and Senior Research Associate at Harvard Graduate School of Education, Harvard University, Project Zero, 315 Longfellow Hall, Cambridge, Massachusetts 02138. His specializations include critical thinking, informal reasoning, and creativity.* TAMAR GLOBERSON *was a Professor of Education at the School of Education at Tel-Aviv University, Tel-Aviv, Israel.*

residues. But any attempt to answer such a question must entail a widening of the research agenda. No computer technology in and of itself can be made to affect thinking. One needs to consider, both theoretically and practically, the whole social and cultural milieu in which instruction takes place. We suggest that the conceptual framework presented here might facilitate the design of educational research and the development of further theory in this domain.

Effects *with* Versus *of* Intelligent Technology

With intelligent technologies becoming prominent, it has not taken long for questions to arise about their impact on human thinking and learning. But the question has not always been clearly asked. To make sense of the question, one must distinguish between two very different ways in which intelligent technologies might have an effect on the reach of human intellect. One way concerns the changes in performance that students display *while* equipped with a technology (i.e., program or tool), for example, the level of sophistication in the hypotheses generated while working with a computerized model-builder (Mandinach, 1989). There, and in many other cases, working with an intelligent tool has effects on *what* students do, *how* well they do it, and *when* it is done (Pea, 1985). We shall refer to such potential effects as effects *with* the technology. Another meaning of "effect" concerns relatively lasting changes in students' general cognitive capacities *in consequence* of interaction with an intelligent technology. This class of effects pertains to subsequent changes in mastery of knowledge, skill, or depth of understanding once the student is away from the computer. We shall refer to such effects as effects *of* the technology.

The distinction between the two kinds of effect can be illustrated by the case of an expert operator of an abacus: On the one hand, the person displays enhanced arithmetic skill while working with the abacus (effect *with* the abacus). On the other hand, the person may display subsequent enhancement while computing without the abacus, because of internalization of procedures initially mediated by it (effect *of* the tool). For another illustration, consider the possible impact of a truly intelligent word processor: On the one hand, students might write better while writing with it; on the other hand, writing with such an intelligent word processor might teach students principles about the craft of writing that they could apply widely when writing with only a simple word processor; this suggests effects of it.

The difference between effects *with* and effects *of* technology has a parallel in the contrasting emphases of scholars who have studied the impact of literacy on cognition. Thus, Havelock (1982) investigated effects with literacy, asking how alphabetic literacy has redefined the roles and functions of memory and empowered it, but not how literacy affected memory capacity. On the other hand, Scribner and Cole (1981), to mention one important study, have studied the effects of literacy on other mental functions and abilities, and thus have assessed the cognitive consequences of literacy.

Although some sources examining the impact of prior technologies address the *with* question and some the *of*, by and large the two have not been juxtaposed and systematically compared. Yet, it is important not to neglect one for the other and not to muddle them together, as has sometimes happened. After all, depending on the circumstances, one or the other could prove profoundly more important. Although it may be the case that the pencil, the slide rule, or the word processor totally redefine the tasks of memorization, computation, or writing, perhaps even profoundly upgrading performance, it does not necessarily follow that they also leave any cognitive residue in the form of improved ability to recall information, compute, or write in their absence. One can plan, design, write, experiment, and simulate in ways not possible until now. But does this partnership make students any smarter, better skilled communicators, or better skilled learners (or, alternatively, less skilled) as a result? We will discuss these issues below, beginning with a discussion of cognitive effects *with* technology, continuing with a discussion of effects *of* it, and concluding with a brief examination of the wider contexts in which such effects need to be studied.

Effects *with* Technology: Intellectual Partnership

Technologies can be divided roughly into two classes, in terms of their afforded use: machines that work for us and tools with which we work (Ellul, 1964). The engine (as distinguished from the whole car), the watch, and the automatic pilot work for us; the pencil, the hoe, the microscope, the camera, the slide rule, the word processor, and the computerized statistical package require that we work with them; they do little for us without our active participation. The latter technologies are of particular interest here, for they, unlike the ones that work for us, afford us an intellectual partnership in which results greatly dependent on joint effort.

The partnership with computer tools entails the three major ingredients one finds in human partnership: (a) a complementary division of labor that (b) becomes interdependent and that (c) develops over time. Moreover, the partnership is genuinely intellectual: As defined by the concept of intelligent technology, the tool assumes part of the intellectual burden of information processing. For example, spread sheets, statistical packages, and graphing utilities provide the expert with powerful facilities that shortcut the cognitive effort required to produce a professional result, as well as allow a less experienced novice to fashion a respectable product.

Moreover, even the novice might gain from certain computer tools that support cognitive processes. Given that higher order thinking operations require automatization of lower level ones (e.g., Anderson, 1983), the partnership with the computer might carry out some of the lower level operations, thus circumventing the need to achieve automatization first. Novices might become liberated to engage in cognitive activities normally out of their reach without the technological partnership (Olson, 1988).

Let us pursue a little further the potential of computer tools that support learning in novices. For example, a tool like STELLA (Richmond, 1985) allows the construction of mathematically based models of economic, historic, ecological, or transportation systems. Variables, values, and their relations are built into a model by the learners. Students do not need to commit anything to memory (a great relief, given the complexity of models that can be programmed with the tool), but they can generate and test the wildest hypotheses about the interrelations among conceptual entities (Mandinach, 1989). The task of learning course material shifts from memorization of discrete ideas, which becomes quite unnecessary, to finding ways to interrelate them. Moreover, this tool allows learners to organize the ideas according to deep rather than

surface criteria, an ability more typical of the expert than of the novice (Chi, Feltovich, & Glaser, 1981).

With such examples on hand, it makes sense to call computer tools that offer an intellectual partnership *cognitive tools* (Pea, 1985) or *technologies of the mind.* They potentially allow a learner to function at a level that transcends the limitations of his or her cognitive system. Such tools let the learner engage in hypothesis testing, designing hypothetical ecological "environments," lab experimentation, planning, intelligently guided writing, solving math problems, and model building on levels rarely possible until now. Indeed, it can be argued that work with specific computer tools might accomplish more than just enabling the beginner to do the same thing faster and with less effort: These tools might redefine and restructure the learning or performance task, much as the pencil has qualitatively restructured the act of remembering (Cole & Griffin, 1980). In sum, the intellectual partnership with such tools can change the ratio between accessing prior knowledge and constructing new knowledge, in favor of the latter (Pea, 1987). The performance of such a partnership between a human and technology could be far more "intelligent" than the performance of the human alone.

The Role of Mindful Engagement

Notice, however, our emphasis on the effects that such partnerships *could* attain. Informal observations of students using technologies such as the Learning Tool (Kozma & Van Roekel, 1986) and STELLA certainly suggest that they provide the opportunity for intelligent partnership, but how often such opportunities are taken in actuality is quite another question. It cannot be assumed that they are seized automatically, even when they are there (Perkins, 1985). Unfortunately, any partnership requires effort, and intellectual partnerships between humans and technology are no exception.

We take it as a basic tenet that for partnering to attain higher levels of intellectual performance, the human's mental processes have to be of the nonautomatic type (Shiffrin & Schneider, 1977). These processes are under the learner's volitional control rather than under that of the task or the materials (Schneider & Fisk, 1984), and they are effort demanding. The employment of such nonautomatic, effortful, and thus metacognitively guided processes has been defined as a state of *mindfulness* (Salomon & Globerson, 1987). It contrasts with a state of *mindlessness* characterized by blind reliance on marked structural features of a situation without attention to its unique and novel features (e.g., Langer, 1989).

Mindfulness is akin to high cognitive capacity usage (Britton, Glynn, Meyer, & Penland, 1982) and to high "constructive effort in learning" (Bereiter & Tinker, 1988), states wherein the person does not rely on already automatized processes but rather on task-specific controlled ones. Thus, for example, when students work with the Learning Tool and seriously consider novel ways of interrelating different concepts, paying careful attention to their generic attributes, they are using the tool mindfully; on the other hand, just spreading out the concepts in a maplike manner and interrelating them in a haphazard way would be a relatively mindless use of the tool.

Recent research (e.g., Bereiter & Tinker, 1988; Langer, 1989; Salomon & Leigh, 1984) has shown that mindful engagement in a task makes learners mobilize more of their intelligence, generate more novel inferences, and commit more of the material encountered to memory. Although this appears to be the general case for learning and for performance with new materials, it is apparently less important when learners are given close guidance and more important when learners are left on their own: In the former situation, mental processes are channeled by instructional processes, whereas in the latter, the employment of nonautomatic processes very much depends on the learners' initiative.

The very idea of working with an intelligent tool is based on the assumption that users explore, design, probe, write, or test hypotheses in ways that couple the tool's intelligence with theirs in mindful engagement with the task. It thus follows that only when learners function mindfully will the upgrading of performance while working with a computer tool take place.

Mindfulness in a partnership with computer tools stems from at least two sources. One source is the general tendency of people to be mindful information processors (Cacioppo & Petty, 1982). A second source, of greater importance here, is the combination of materials, task, and means that stimulate mindfulness. For example, Malone and Lepper (1987) have studied attributes of computer games that increase intrinsic motivation, expecting them also to increase mindful engagement in the process. Some of these attributes—control of the activity, interactivity, immediate results, graded goals, conflict, moderate uncertainty, and the like—are present not only in games but also in intelligent computer tools. Indeed, this follows directly from their nature: They face the user with choice points that invite mindful consideration, and they confront the learner with cases of conflict that are likely to trigger mental experimentation (Gelman & Brown, 1986). Still, this does not mean that one could not use the tool in a mindless trial-and-error fashion; the more open-ended the activities afforded by a tool, the more freedom the learner has in becoming, or not becoming, mindfully engaged in them.

Support for the latter contention comes from a recent doctoral study carried out by Rachel Mintz (1988) at the Tel-Aviv University. She found in that study substantial correlations between (self-reported) effort expenditure and learning outcomes when student worked with a fully interactive ecology simulator. When students worked with a noninteractive simulator, initial ability but not effort expenditure best predicted learning outcomes. These findings suggest that some students, possibly the ones not mindfully inclined (Cacioppo & Petty, 1982; Salomon & Globerson, 1987), do not expend effort even when given the opportunity for real partnership with an intelligent tool that engages others in a mindful exploratory process. As Chanowitz and Langer (1980) have observed, "The apparently structured environment *suggests* certain modes of humanly minded engagement, but it does not *dictate* that mode" (p. 102).

In sum, although intelligent computer tools offer a partnership with the potential of extending the user's intellectual performance, the degree to which this potential is realized greatly depends on the user's volitional mindful engagement. It is not only what students are interacting with but also *how* they do it.

The Question of Ability

Given sufficiently mindful engagement in the partnership,

strong effects of working with an intelligent technology can be expected. However, such partnerships challenge our traditional notions about ability. Usually we view ability, regardles of definition, as the potential of a person's mind, the property of the individual. But, once we couple intelligent technologies with a person's ability, the emphasis might shift to examining the performance of the joint system. After all, the *system,* not the individual alone, carries out the intellectual task (Pea, 1987, 1989).

Such a reconceptualization of human ability appears at first to be quite novel. But closer examination reveals that we have implicitly accepted it all along. As Olson (1986) points out, "Almost any form of human cognition requires one to deal productively and imaginatively with some technology. To attempt to characterize intelligence independently of those technologies seems to be a fundamental error" (p. 356). For example, we would not think of testing people's artistic ability without the use of some medium such as brush and paint. As Pea (1989) has recently pointed out, once appropriate intellectual tools are employed, ability becomes distributed by "off loading" some of the mental operations required unto the artifactual environment.

By analogy, then, we should be willing to conceive of intellectual ability as a property of a joint system—a human working with an intelligent technology. Yet, this extrapolation is not so unproblematic as it may seem at first. What would we say of a partnership of individual and intelligent technology that performs well but leaves the human partner to persevere with a naive preconception when functioning without the technology (e.g., Gentner & Gentner, 1983)? Moreover, what if the technological component contains sufficient expertise actually to *decrease* the intellectual share of the human partner, as is nowadays the case with expert piloting systems that supplant the human pilot during dangerous landings? What if expert systems for medical diagnosis become so smart that they reduce the novice physician to the role of data feeder?

Such dilemmas can be resolved by defining two ways to evaluate the intelligence of partnerships between people and technology: *systemic* and *analytic.* The systemic approach examines the performance of the whole system and judges the products of its joint intelligence without distinguishing the contribution of the human partner from that of the technology. In contrast, the analytic approach examines the specific kinds of mental processes that the human partner contributes. For example, how does a learner, equipped with a simulator that allows the manipulation of complex clusters of variables, test hypotheses about the interrelation among different ecological variables (e.g., Mintz, 1988)?

From a systemic point of view what counts is the overall level of performance of the system, not of the individual in it; ability is treated as the joint product of person and computer tool. The blind spot of this approach is that, once tools become sufficiently intelligent, one may lose sight of the individual's unique contribution, and the unsettling cases pointed out above may occur.

In contrast, by using an analytic approach, we can continue to conceive of ability as the property of individuals and can evaluate the ability manifested by them while working with an intelligent computer tool. To cite Vygotsky (1978), an opportunity to work with an intelligent computer tool could be seen as an invitation to operate within a zone of proximal development. The partnership with the technology is like the one with a more capable peer: It allows mindful learners to engage in cognitive processes that are of a higher order than the ones they would display without that partnership. The individuals' performance is still assessed, but under conditions that allow them to stretch their cognitive muscles to the maximum.

The question of how to define ability can thus receive two answers. One answer adopts the systemic approach, appraising the products of the joint abilities of person and tool. The other answer adopts the analytic approach, appraising the kinds of mental activities contributed by the individual operating in partnership with the intelligent tool. The latter is more oriented toward the study of human potential and toward educational concerns. It favors the instructional use of cognitive tools that afford higher order mental engagement, as might be the case with STELLA and the Learning Tool, rather than with tools that upgrade performance of the system but not of the individual.

Effects *of* Technology: Attaining Cognitive Residue

Although the distinction between systemic and analytic perspectives helps to resolve the puzzle of defining ability when people work *with* technologies, it does not address the effects *of* technologies on cognition. Indeed, the effects *of* technology are quite a different matter. A system designed to improve diagnosis or to redefine the process of writing when one works *with* it is not necessarily the best system to cultivate diagnostic or writing skills of the individual. One could argue, at this point, that the distinction between effects *with* and *of* is no more than a temporal one; after all, it might be argued, soon we are likely to have such powerful computer tools that all effects will be with them, and thus the question of cognitive residue as a consequence of this partnership will become a somewhat irrelevant one.

Indeed, the contrast between *with* and *of* creates a dilemma of choice. Perhaps all we should aim at are effects *with* a technology whereby intelligence is truly distributed (Pea, 1989), thus emphasizing the systemic aspect of human ability. If individuals plus technology can now accomplish tasks they were unable to accomplish before, the question of what residues the partnership with the technology leaves might be moot. As Olson, Torrance, and Hildyard (1985) argue with respect to literacy, "it is misleading to think of literacy in terms of consequences. What matters is what people do with literacy, not what literacy does to people" (p. 15). The same could be argued with respect to intelligent computer tools.

However, this seems too radical a step for the present state of technology. Until intelligent technologies become as ubiquitous as pencil and paper—and we are not there yet by a long shot—how a person functions away from intelligent technologies must be considered. Moreover, even if computer technology became as ubiquitous as the pencil, students would still face an infinite number of problems to solve, new kinds of knowledge to mentally construct, and decisions to make, for which no intelligent technology would be available or accessible. Dilemmas and questions such as "How much more should I prepare for the test?", "What will my readers think of this argument?", "How do I fit my present perceptions of the USSR with the views I entertained until now?", or "How come electricity does not fatigue going up the Empire State Building?" need an independent and capable thinking mind, not one that constantly depends on the partnership with technology, intelligent as it might be.

The cognitive effects *of* the interaction with computer tools pertain to the cultivation of such skills and abilities. Thus, consider the possibility that the intellectual partnership with a computer tool can leave a *transferable* cognitive residue in the form of, for example, a generalized ability for self-regulation and guidance (Bereiter & Scardamalia, 1987; Salomon, Globerson, & Guterman, 1990). Such an improved ability would serve the individual in numerous instances, particularly when on his or her own. Similarly, individuals' better solo mastery of strategies and skills might allow them to become involved in higher order activities in subsequent partnerships with intellectual tools.

Accordingly, the impact *of* a technology is as much a concern as performance *with* it. To be sure, we want to see learners work more effectively *with* computer tools, but we also want to see a positive cognitive impact *of* computer tools. Students should not only become better writers when equipped with an intelligent writing tool or idea generator; they should also become better able to write when using no more than a simple word processor that provides no intelligent guidance or even when writing with only pencil and paper. Relating this concern to the question of how to conceive of intelligence as seen from an educational point of view, we need to adhere to the analytic approach, emphasizing the cognitive residues of intellectual partnership, the ones that a student may carry away from it.

However, the possibility of a cognitive residue rests on an important assumption. The assumption is that higher order thinking skills that are either activated during an activity with an intellectual tool or are explicitly modeled by it can develop and become transferred to other dissimilar, or at least similar situations. This expectation for transferable cognitive residue rests itself on a more basic assumption that, contrary to some views (e.g., J. S. Brown, Collins, & Duguid, 1989), cognitive skills of the kind one would want to cultivate in school are not necessarily context-bound or "situated" (Perkins & Salomon, 1989). The question is, does any evidence support the existence of such side effects of technology use?

Intelligent Technologies and the Question of Transfer

Regarding "old" technologies, the case is not easy to make. These technologies—writing, television, and so on—are so widespread and their presence so correlated with other sociological factors that experimental manipulations are hard to mount, and reasonably clean "natural experiments" hard to find. A rare exception is a recent large-scale quasi-experimental study concerning the effects of print literacy on the mastery of cognitive processes (Scribner & Cole, 1981). The Vai, a Liberian tribe, have a writing system mastered by many members of the culture, but no formal schooling. This situation presents a nice opportunity to separate literacy per se from the confounding variable of schooling. The Scribner and Cole study yielded provocative results: No general cognitive consequences of literacy were found.

But then, as the authors point out, literacy among the Vai does not play as central a social and cultural role as it does in our culture. As the authors suggest, it may be that for a technology to affect minds it needs to be of vital importance and to serve many purposes in people's lives. Moreover, the informal *teachers* of the Vai script did show cognitive spin-off effects. Perhaps the ordinary learners were not sufficiently mindful in their mastery of the script for a broader cognitive impact, but their teachers, coping with the considerable demands of instruction, were.

Even when technology serves a central societal role, it may not affect minds right away. Literacy, as Olson (e.g., 1986) points out, may have forced upon us a sharp distinction between what is said or written and what is meant by it. Illiterate societies, as he argues, do not make such a fine distinction. But such effects, assuming that they are indeed the result of literacy and print, did not develop overnight, not even over the span of one generation just introduced to literacy. Unfortunately, such long-term processes do not lend themselves to observation and measurement. Socio-historical analyses like those offered by Havelock (1982) or Goody (1977), while very suggestive, do not provide the empirical evidence one would like for the effects of technology on the mind.

Although effects of technology are difficult to assess in the case of older technologies, the new intelligent technologies offer more promising prospects. First of all, formal controlled experiments are relatively easily conducted because most individuals have not had much contact yet with the new technologies. Second, some of the intelligent technologies aim to cultivate intelligent behavior with a directness not found in the older technologies of writing or telecommunications: Certain current and developing intelligent technologies directly and effectively guide the user in the deployment of generally applicable thinking strategies, even further cultivating them (e.g., Mandinach, 1989; Salomon et al., 1990; Zellermayer, Salomon, Globerson, & Givon, in press).

Still, findings pertaining to what we define as cognitive effects *of* computer technology are ambiguous. Whereas some studies show the expected transfer of skills acquired during partnership with computer tools (e.g., Levin, Riel, Miyake, & Cohen, 1987; Salomon et al., 1990), others have either failed to show such cognitive residues (e.g., Pea, Kurland, & Hawkins, 1985) or have found them only among high-ability students (e.g., Mandinach & Corno, 1985; see a review by Krendl & Lieberman, 1988). Perkins and Salomon (1987) and Salomon and Perkins (1989) have examined studies that have and have not found transferable cognitive residues resulting from the intellectual partnership with computer tools and programs or from other instructional interventions. They suggested that the main difference between the two clusters of studies lies in the qualitative ways students engaged in the partnership or the instruction. They argued that some transfer can be attained by much and varied practice to near skill automaticity by means of what J. Anderson (1983) has described as "skill generalization." However, most instructional and experimental situations do not and cannot provide such extensive practice. On the other hand, in situations in which students become engaged in mindful abstraction of procedures, self-regulation, or strategies of the kind activated or modeled during the partnership, transfer of these does take place. Although people rarely engage in such mindful processing when using a technology under normal noninstructional circumstances, it can be provoked. For example, in cases of instruction in computer programming where mindful abstraction (Salomon & Perkins, 1988) has been cultivated by the instruction, impressive transfer has been found (Clements & Gullo, 1984).

This and related research with computer tools (e.g., Salomon et al., 1990) has demonstrated more what transferable effects the partnership with computer tools and programs *can be made* to have than the effects it actually does

have under more natural conditions of daily employment. These findings suggest that "Is there a cognitive effect of technology?" may be the wrong question to ask when one is seeking transfer in school settings: The needed mindful abstraction is not likely to occur spontaneously. One might better ask, "Can a cognitive effect of technology be 'engineered' by designing the technology, the activity, and the setting to foster mindful abstraction of thinking skills and strategies?"

The Wider Context of Technology's Effects

The initial question—does computer technology have any effect on students' intellectual performance and ability—has now been reframed. First, we differentiated between effects *with* and effects *of* computer tools, a contrast that can better focus research questions, as well as challenge our notions about human ability. Second, we examined the preconditions for positive effects *with* and *of* an intelligent technology, for example, the importance of mindful engagement and reflective abstraction.

Although all this speaks to the question, the discussion so far has focused on technology itself and the independent variable of interest. A broader framing is needed because the import of technology for human intelligent functioning inevitably and demonstrably depends on factors beyond the compass of the technology itself. We can see here at least three relevant contexts: the normative, the theoretical, and the practical.

The Normative Context

If positive effects of intelligent technology are possible, what about negative ones? March (1987) speaks of "deskilling," which results from work with intelligent tools that numb, so to speak, certain skills needed before but not with the tool. Some of these, such as procedural knowledge for the derivation of a square root, could perhaps become deskilled. However, returning to an issue discussed earlier, what if an expert system becomes so intelligent as to numb physicians' own diagnostic skills?

This may be of litle concern when seen from a systemic point of view. All that matters is the improved diagnostic performance of the *system*. But seen from an analytic perspective, particularly when coupled with normative and educational concerns, the issue demands careful consideration. What if, indeed, human diagnostic abilities give way to a mechanical facility in operating black-box expert systems? In our eagerness to produce ever more intelligent tools, we might inadvertently deskill skills we would want to retain. As already pointed out by Rollo May, not everything possible is necessarily desirable. And as argued by Sarason (1984), "Because something can be studied or developed is in itself an insufficient base for doing it however wondrous it appears to be in regard to understanding and controlling our world" (p. 480).

The Theoretical Context

The normative issues point the way toward an inevitable conclusion: From the standpoint of theory building, the impact of intelligent technologies on human performance needs theories of great compass, taking into account technological, individual psychological, and social variables. Indeed, no technology, computer technology included, affects individuals' minds except through the specific mental operations they employ. Recalling the viewpoint of Leont'ev (1981), Vygotsky's student, we might say that these operations—planning, hypothesis testing, responding to intelligent metacognitive guidance—are subsumed under one's goal-directed activities—programming, writing, model building—which themselves are strongly affected by the culture that prescribes, sanctions, and promotes them. Neither mental operations nor the activities that tap them exist in a cultural vacuum.

Consider the dramatic absence of any significant literacy effects on the cognitions of Scribner and Cole's (1981) Vai subjects. As the authors point out, literacy was practiced by the Vai in rather limited ways in comparison with our society. It served a few noncritical social and commercial functions; nothing critical depended on it, and nothing new has been introduced into the Vai culture by it. So one could not infer from these findings that literacy has no effect on its users' cognitions. The more plausible conclusion is that literacy will affect minds only in cultures literate through and through, where literacy is practiced in a wide variety of instances, in a wide range of activities, and for a wide range of purposes (Scribner & Cole, 1981).

Moreover, technology, modes of activity, cognitive effects, and culturally prescribed functions for that technology are surely reciprocally interrelated. If you have a technology, as H. Simon (1987) has observed, you are likely to use it. And with this initial use, old activities might become redefined (e.g., writing with a word processor), new activities emerge (e.g., programming), and the roles for the intellect become changed (e.g., from "knowledge" as possession to "knowledge" as an activity denoting retrieval from data bases). This, in turn, is likely to affect the cultural milieu which, in turn, may redefine the roles played by the technology.

Accordingly, if computers become as central in education as some predict they are bound to, the whole culture of school is likely to change—from knowledge imparting to self-guided exploration and knowledge recreation—and such a change would in turn change the place of computers in schools, disclosing important and often unexpected roles for them. In some cultures, institutions, environments, and subcultures, the computer might become the "defining technology" of the time (Bolter, 1984), affecting the kind of activities individuals become engaged in and the ways they carry them out; in others, the computer might remain an unimportant add-on, thus limiting its potential effects.

Examination of the effects *with* and *of* intelligent technologies stands to benefit from widening the theoretical perspective to include cultural context as a source not only for distal independent variables but also for variables that interact with each other simultaneously (Cole, 1985) in what Scarr (1985) has called "a cloud of correlated events." Controlled experiments may show that certain effects can be engineered under favorable conditions. They can also suggest possible mechanisms, such as internalization or aroused mindfulness, that might mediate the effects. However, such experiments do not tell us what happens—or can be made to happen—under natural conditions where powerful roles are played by the cultural, social, and institutional contexts.

The Practical Context

This leads us to a brief discussion of the practical contexts in which technology may affect minds. In light of our discussion of the theoretical context, it becomes apparent that pro-

found effects of intelligent technology on minds can take place only when major changes in the culture take place as well. No important impact can be expected when the same old activity is carried out with a technology that makes it a bit faster or easier; the activity itself has to change, and such a change cannot take place in a cultural vacuum.

But this means that it is not the technology alone affecting minds but the whole "cloud of correlated variables"—technology, activity, goal, setting, teacher's role, culture—exerting their combined effect. Consequently, to engineer a desirable effect either *with* or *of* an intelligent technology requires a lot more than just the introduction of a new program or tool. For example, Daiute (1985, 1988; Daiute & Kruidenier, 1985) has shown that the introduction of word processors into classrooms in itself has only a minor impact—primarily, more "local editing" to correct spelling and grammar. Students do often find that they have something additional to say, but then tack it onto the end rather than integrating it with the structure of the piece. In contrast, when the technology or teachers provide direct prompts encouraging structural revision, students respond with more thoughtful reworking of wider scope.

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For another example, Papert (1987) has described two schools in which Logo was introduced. One school treated Logo as just another subject matter to be mastered, while the other used Logo as material to "mess around with." Although students in both schools learned Logo, the kinds of activities and the learning cultures—didactic learning versus exploration—were dramatically different. One would not be surprised if the first school yielded no important effects of technology, whereas the second did. Indeed, Harel (1988) demonstrated such a contrast in students studying Logo and fractions arithmetic in a more didactic versus a more constructivist and integrated manner; she found that the latter yielded much deeper mastery of Logo and understanding of fractions. Thus, not Logo in and of itself but Logo in a cultural surround orchestrating goal setting, integration with subject matter, and related factors affected cognitions.

Conclusion

In this age of making machines more intelligent, we began by asking whether machines can make people more intelligent. The answer we suggest is yes, and in more than one way. Effects *with* technology can redefine and enhance performance as students work in partnership with intelligent technologies—those that undertake a significant part of the cognitive processing that otherwise would have to be managed by the person. Moreover, effects *of* technology can occur when partnership *with* a technology leaves a cognitive residue, equipping people with thinking skills and strategies that reorganize and enhance their performance even away from the technology in question.

However, this affirmative answer comes with a large caveat: Such benefits are not likely to occur automatically as technologies advance. Rather, they need to be cultivated through the appropriate design of technologies and their cultural surrounds. For example, technologies that help users to reorganize their writing-related cognitions into new and more powerful patterns (Zellermayer et al., 1990) are more likely to help than are technologies that simply provide convenient working environments (e.g., a word processor). Technologies and cultural surrounds that foster mindfulness are more likely to yield cognitive residue than are technologies that let the user lapse into mindlessness. Moreover, when benefits do accrue, they bring with them problems that need sorting through—for example, the risks of inappropriate deskilling, the need to rethink what intelligence means.

Of course, neither the necessity of designing for the benefits nor the need to confront some puzzles of principle should dismay us. It is naive to speak of the effects of technology as a natural and inevitable phenomenon to be studied, logged, and analyzed. Within the constraints of possibility and practicality, the effects of technology are what we choose to make them, and the responsibility of decision comes with the opportunity of choice.

Accordingly, to make the most of the opportunity, a partnership is required not only between people and machines but among people of different expertise. While investigators in artificial intelligence and related fields continue to develop cognitive tools, experts in instruction, researchers concerned with education and human performance, sociologists sensitive to patterns of cultural interaction, and even philosophers engaging questions of meaning and ethics will need to bring their judgment and skills to bear. As the tale unfolds in time, we forecast a somewhat tortuous path to outcomes both salubrious and surprising.

Note

A brief and modified version of this paper was presented as an invited address by Gavriel Salomon to the Annual Meeting of the American Educational Research Association (April, 1988) and was published in part in the *Proceedings of the 24th International Congress of Psychology* (Vol. 4). The writing of the article was supported by a Spencer Foundation grant given jointly to Gavriel Salomon and to the late Tamar Globerson, who met a sudden and untimely death while this article was being written.

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